A NEW SPECIES OF PINUS FROM MEXICO AND CENTRAL AMERICA

J. P. PERRY, JR.[1]

A new species of *Pinus* is described from Mexico and Central America. Specimens were collected in Mexico, Guatemala, El Salvador, and Honduras, and resin samples were taken from trees in Mexico (Chiapas), Guatemala, and Honduras. This species differs from *P. pseudostrobus, P. oaxacana,* and *P. estevezii* both in turpentine chemistry and in leaf and cone morphology. Throughout most of its range, associated species were often *P. pseudostrobus, P. oaxacana,* and *P. montezumae*; field observations indicate that natural hybridization probably occurs between the new species and these taxa.

While carrying out field studies on species of *Pinus* growing in Mexico and Central America, I discovered a number of populations of the genus in Mexico, Guatemala, El Salvador, and Honduras that appear to belong to an undescribed species.

Pinus nubicola J. P. Perry, sp. nov. FIGURES 1–4.

Differt a P. oaxacana et P. estevezii foliis 25–40 cm longis, in fasciculo 5 vel 6 (interdum 7), cernuis vel pendulis; et squamis 20–25 mm latis, ad apicem prominentiis disparibus et umbone parva cum margine depressa instructis.

Tree 25–30 m tall, d.b.h. 0.5–1 m, when mature with open, rounded crown. Spring shoots uninodal; branchlets puberulent, soon becoming glabrous; young trees with smooth bark. Leaves in fascicles of 5 or 6 (occasionally 7, rarely 8), 25–43 cm by 0.6–1 mm, flexible, very drooping, margin serrulate; stomata on all surfaces; hypodermis 2- to 4-layered, with many slight penetrations into chlorenchyma; resin canals 3 or 4, medial (occasionally 1 internal); endodermis with outer cell walls thickened; vascular bundles 2, distinct; fascicle sheaths persistent, 20–30 mm long, pale brown, not resinous. Cones subterminal, 1 to 4 together, subsessile, reflexed, asymmetrically ovoid to long-ovoid, 10–15 by 8–10 cm when open at maturity, peduncle and few basal scales remaining on branch when cone falls. Scales 20–25 mm wide, thick, stiff, with apex obtusely angled, generally with distinct, unequal marginal projections; apophysis 5–8 by 20–22 mm, transversely keeled, abaxial surface raised more than adaxial, the umbo ashy gray, central, 2–3 mm long, margins often slightly depressed, generally curved upward, terminating in small, persistent prickle. Seeds brown or spotted to mottled black, 5–7 by 4–5 mm, with detachable, pale brown wing 20–25 by 8–11 mm; cotyledons (7 or) 8 to 10 (to 13).

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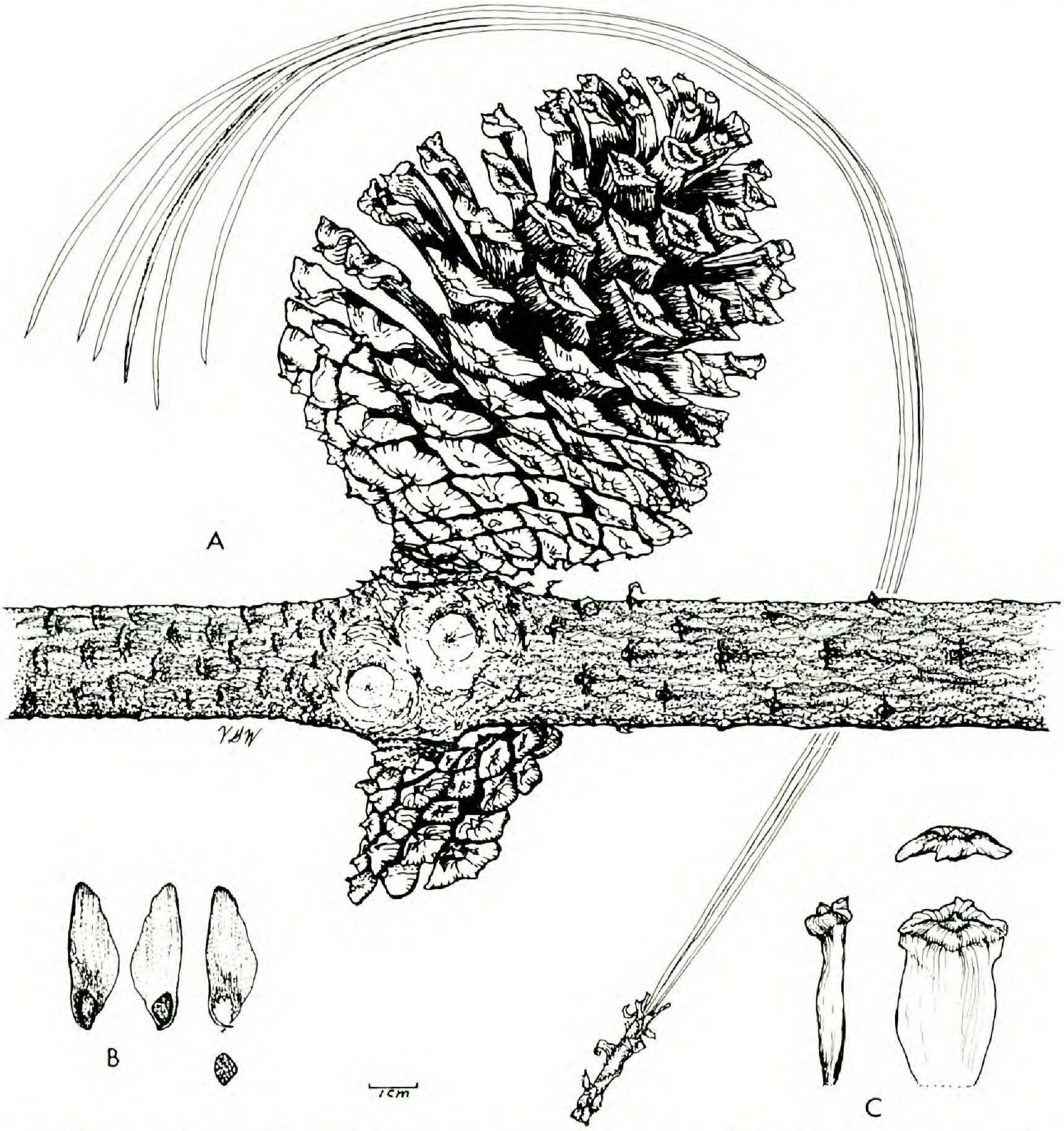


FIGURE 1. *Pinus nubicola:* A, mature cone, foliage, and branchlet, showing nondecurrent bases of foliage bracts; B, seed and seed wing; C, cone scale, showing apophysis, umbo with depressed margins, and apex with unequal projections.

TYPE. Guatemala, Depto. Guatemala, about 40 km E of San José Pinula on dirt road toward Las Nubes, 90°20′W, 14°33′30″N, alt. 2000 m, 25 Feb. 1979, *Perry GUA.32-79* (holotype, GH; isotypes, CHAP, E, GH, K, MEXU, NCSC).

TURPENTINE ANALYSES. Most trees had relatively large amounts of heptane, nonane, and α-pinene; many also had sizeable quantities of limonene, while a few had a great deal of terpinene-4-ol and methyl chavicol. Results of individual analyses performed on 31 specimens from Mexico, Guatemala, and Honduras, as well as approximate mean percent composition, are shown in TABLE 1.

PHENOLOGY. Flowering starting late January, but mainly February and March.

HABITAT AND DISTRIBUTION. Mexico to Honduras (see MAP 1), on cool, moist mountain slopes, 1800–2400 m alt. (see FIGURE 2).

In Veracruz state, Mexico, *Pinus nubicola* was growing at 1800 m on the

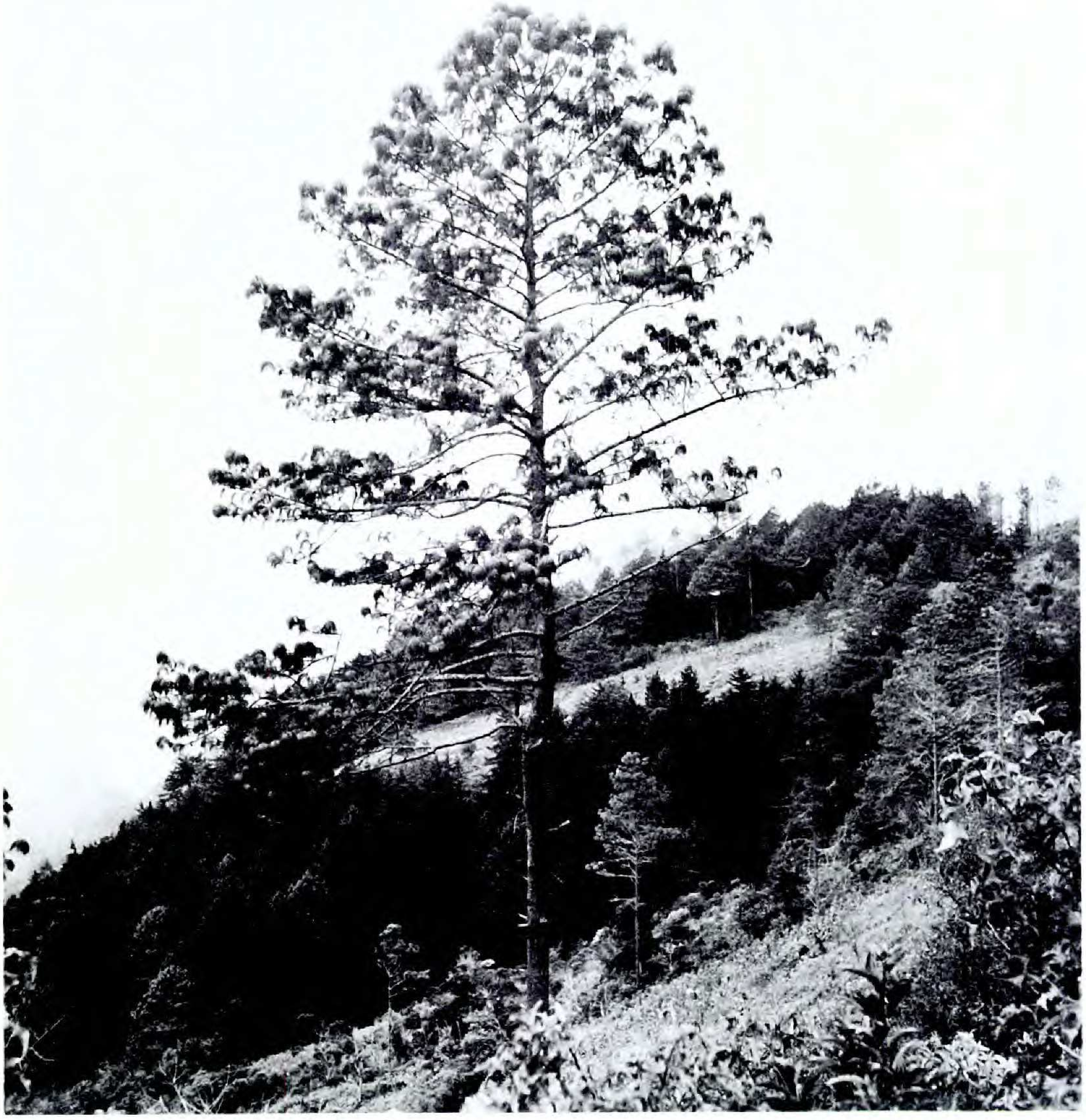


FIGURE 2. *Pinus nubicola* growing on slope of Mt. El Pitál, Depto. Chalatenango, El Salvador, showing characteristically drooping foliage.

humid eastern escarpment of the Sierra Madre Oriental. Associated species were *Pinus chiapensis* (Martínez) Andresen, *P. pseudostrobus* Lindley, *P. oaxacana* Mirov, and *Liquidambar styraciflua* L. In Mexico (Chiapas), at a somewhat drier site, associated species were *P. oaxacana, P. pseudostrobus, P. montezumae* Lambert, *P. rudis* Endl., *P. patula* var. *longepedunculata* Loock,[2] *Pinus oocarpa* var. *ochoterenae* Martínez, *Pinus ayacahuite* Ehrenb., and *Quercus* spp. In Guatemala associated species were *P. oocarpa* var. *ochoterenae, P. montezumae, P. rudis, P. maximinoi* Moore, *P. pseudostrobus* (rarely), and *P.*

[2]Styles (1976) pointed out that there has been considerable confusion in the literature and in the field regarding the identification of *Pinus oocarpa* var. *ochoterenae* and *P. patula* var. *longepedunculata.* He attempted to resolve this by combining the two taxa and referring them to *P. patula* Schldl. & Cham. Although there is indeed a great deal of confusion regarding identification of the two taxa, I do not believe the matter has been clarified by referring both varieties to *P. patula.* I prefer, pending the results of further studies, to use the original varietal classification of these taxa.

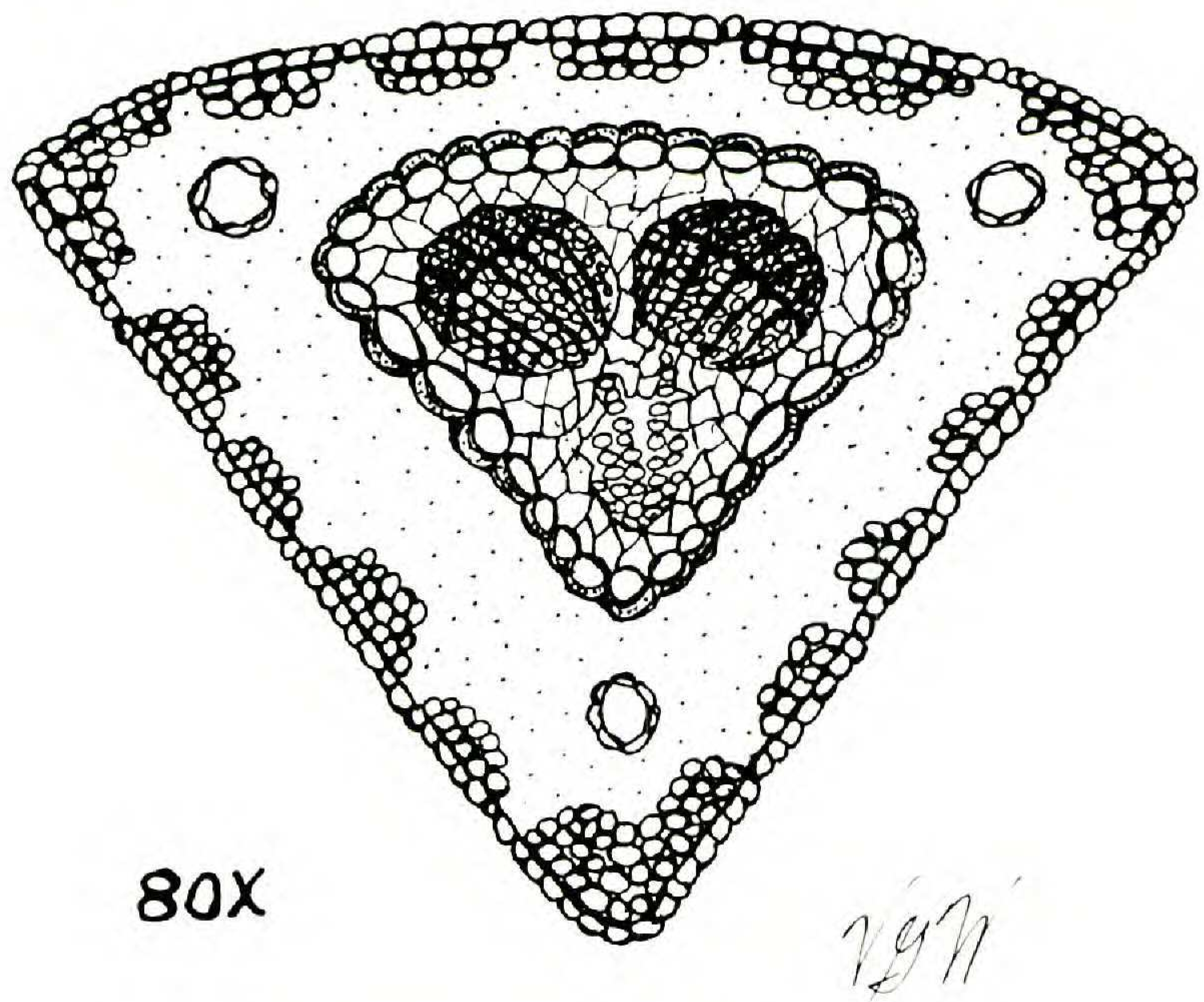


FIGURE 3. Cross section of leaf of *Pinus nubicola.*

tecunumanii Eguiluz & Perry. In El Salvador the species was found growing with *P. maximinoi, P. oaxacana, P. ayacahuite, P. oocarpa* var. *ochoterenae, P. tecunumanii, Abies guatemalensis* var. *tacanensis* Martínez, *Cupressus lusitanica* Miller, *Liquidambar styraciflua,* and *Quercus* spp. In Honduras associated species were *P. maximinoi, P. oaxacana,* and *P. tecunumanii.* At most locations epiphytes were growing in large numbers on the branches and trunks of the trees. In Guatemala and El Salvador some of the larger oaks with massive, horizontal branches were almost covered with orchids and bromeliads. Unfortunately, in most locations—particularly in Guatemala and El Salvador—the forests were rapidly disappearing as the trees were cut for lumber and firewood and the land was converted to pasture and crops.

SPECIMENS EXAMINED.[3] **Mexico.** VERACRUZ: ca. 15 km W of Jalapa, 1800 m alt., *Perry M96-81, M96-81A.* CHIAPAS: ca. 18 km S of San Cristóbal de Las Casas, 2200 m alt., *Perry MEX.24-79*; 15 km N of Comitán, 2200 m alt., *Perry MEX.25-79*; 20 km S of San Cristóbal de Las Casas, 2200 m alt., *Perry MEX.26-79*; E of San Cristóbal de Las Casas, vic. of Las Piedrecitas, 2400 m alt., *Perry MEX.151-83*; ca. 10 km W of San Cristóbal de Las Casas, near Hwy. 190, 2300 m alt., *Perry MEX.74-83*; S of San Cristóbal de Las Casas, vic. of Teopisca, 2300 m alt., *Perry MEX.84-84.* **Guatemala.** QUEZALTENANGO: vic. of Quezaltenango, 2300 m alt., *Perry GUA.3-78.* SOLOLÁ: ca. km 140 W of Guatemala City, 2400 m alt., *Perry GUA.17-78, GUA.19-78*; W of Quezaltenango on hwy. toward San Marcos, ca. km 232, 2300 m alt., *Perry GUA.24-78.* JALAPA: on dirt road from San José Pinula to Mataquescuintla, 2300 m alt., *Perry GUA.112-78* (NCSC), *GUA.112-78A*; E of San José Pinula on dirt road, vic. of Las Nubes, 2200 m alt., *Perry GUA.113-78*; on dirt road from San José Pinula to Las Nubes, ca. km 38, 2250 m alt., *Perry GUA.28-79*; E of San José Pinula on dirt road near Soledad Grande, ca. 2200 m alt., *Mittak 8299* (BANSEFOR[4]); E of San José Pinula on dirt road, vic. of La

[3]Specimens listed are in addition to those collected as vouchers for the trees tapped for oleoresin. Unless indicated otherwise, they are located in the author's personal herbarium.
[4]Banco Nacional de Semillas Forestales, Guatemala.

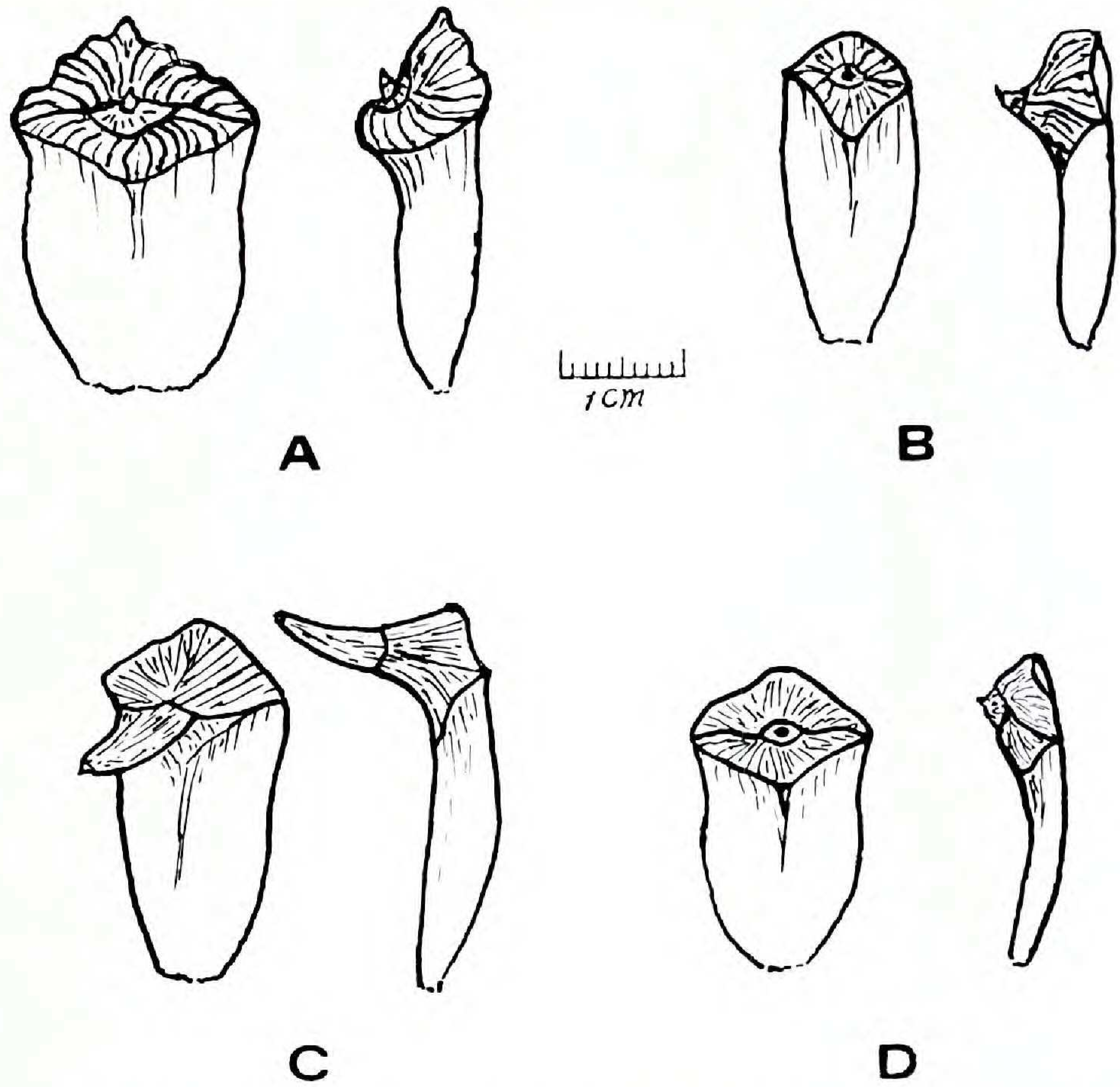


FIGURE 4. Cone scales: A, *Pinus nubicola*; B, *P. estevezii*; C, *P. oaxacana*; D, *P. pseudostrobus.*

Lagunilla, ca. 2100 m alt., *Mittak 9017* (BANSEFOR). **El Salvador.** CHALATENANGO: near Miramundo, 2200 m alt., *Perry SAL.7-77*; near El Aguacatál, 2000 m alt., *Perry SAL.8-77.* **Honduras.** LA PAZ: vic. of Las Trancas, *Perry H-8, H-10* (ESNACIFOR).[5]

RELATIONSHIPS OF PINUS NUBICOLA

Pinus nubicola, with its slender, pruinose branchlets and its smooth-barked young trees, readily falls into the Pseudostrobus group of Mexican pines, which has been variously called a section (Martínez, 1948), a "group" (Loock, 1950; Stead, 1983a; Stead & Styles, 1984), and a "complex" (Mirov, 1967; Stead, 1983b). The other species in the group are *P. douglasiana* Martínez, *P. maximinoi* H. Moore, *P. pseudostrobus, P. oaxacana,* and *P. estevezii* (Martínez) Perry.[6] As determined through chemotaxonomic studies of many of these taxa by Mirov (1958, 1961, 1967), Coyne and Critchfield (1974), Brümmer (1978), Mittak and Perry (1979), and Perry (1982), *P. oaxacana* and *P. estevezii* are most closely related to *P. nubicola.*

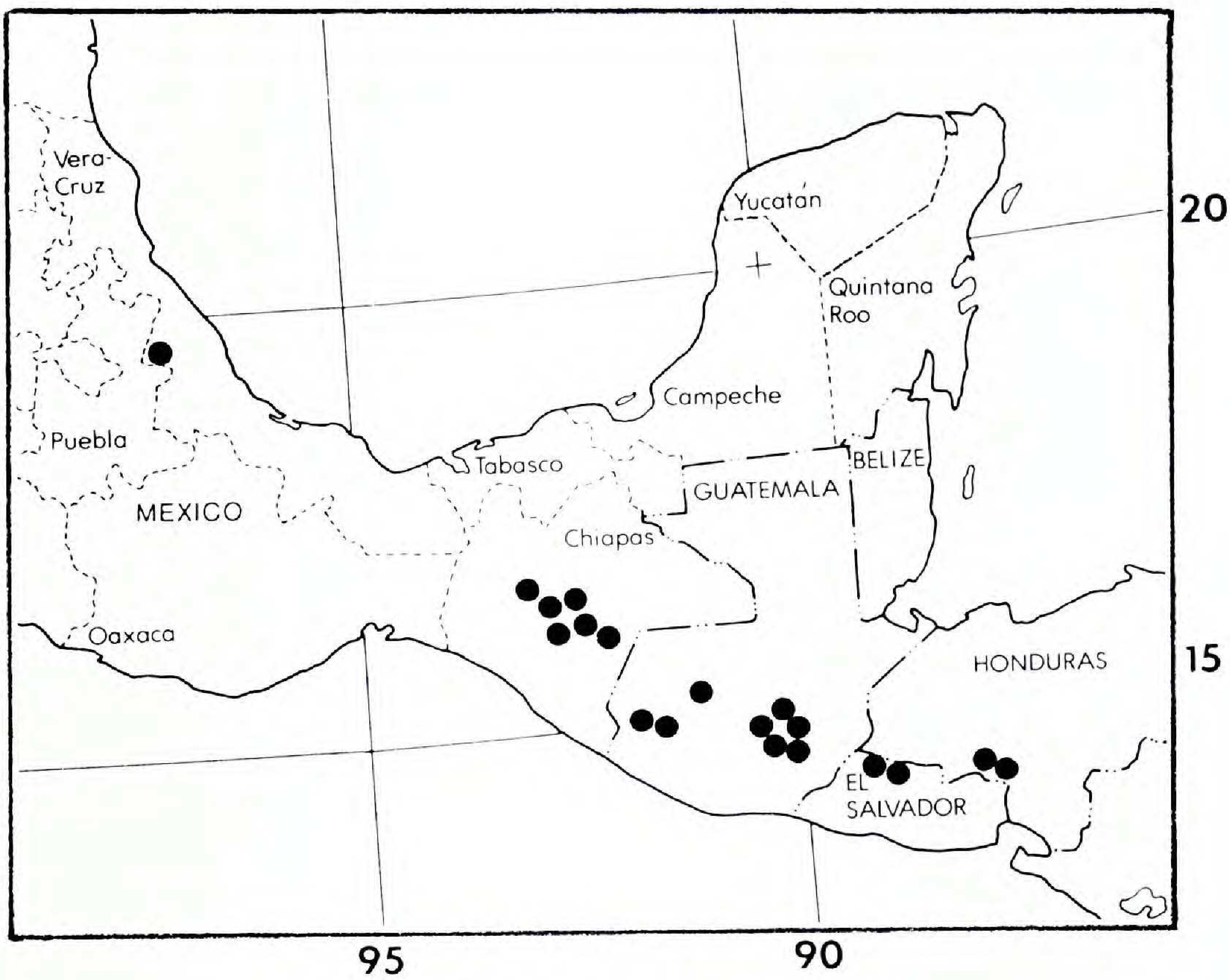
[5]Escuela Nacional de Ciencias Forestales, Siguatepeque, Honduras.
[6]Stead and Styles (1984) criticized the use of resin chemistry by Mirov (1958) and Perry (1982) in elevating var. *oaxacana* and var. *estevezii* to specific status.

TABLE 1. **Turpentine composition* of xylem oleoresin from Pinus nubicola.**

POPULATION	Sample number	Heptane	Octane	Nonane	α-pinene	Camphene	β-pinene	Δ^3-carene	Myrcene	α-terpinene	Limonene	β-phellandrene	P-cymene	Terpinolene	Terpinene-4-ol	Methyl chavicol	α-terpineol
MEXICO																	
Chiapas	1B	25		12	28		10	1		3					18	2	1
State	2B	10		12	31		9	3		30					2	1	
West of San	3B	34		14	6		3	2			39					1	
Cristóbal de	4B	34		15	31		6	7		1					5	1	
Las Casas	5B	5		2	4		2	2			84				Tr	1	
	6B	6		13	8						64					8	
	7B	13		7	44	5	7	7			6	Tr		3	7	1	Tr
	8B	2		12	43		9	3		4					21	6	Tr
	9B	7	8		33		7	8		16				2	4	6	9
	10B	27		11	36		6	2		1					12	4	
	11B	39		12	34	Tr	3	3		3					5	1	Tr
	12B	3		12	54						16	4			3	5	3
	13B			2	81		6								Tr	10	Tr
Station San	M6083	51	Tr	17	12		1	1			6		Tr		7	5	
José	M7283	15		8	36		5	3			21		1		8	1	
	M7383	8		5	39		1	4			31			1	7	4	Tr
Station Las	M12483	9		6	30		8	15			26		1		3	1	
Piedrecitas	M14283	6		12	13			1			40			3	18	4	1
	M15283	12	11	Tr	5			3			53				6	11	
	M14883	7		3	3	1	8	7		64			1	Tr	4	Tr	
GUATEMALA																	
East of	2A	26		8	44		8	Tr		1	2	2			1	4	4
San José	3A	19		12	18		8			3	31				5	2	1
Pinula	4A	42		8	39		6					2				1	
	6A	31	Tr	11	16		10	1		4	17	6			1	2	
	7A	40		8	30		1	1			20					Tr	
	8A	39		15	9		6	1		4	23					2	
	10A	21		10	38		4	3	8	3	13					Tr	
	11A	27		13	24		9	1	6	4	5				10	1	
	12A	32		18	28	4	5			8		4				1	
HONDURAS																	
Las Trancas	H8	42	3	30	5	3	3		Tr	4				2			Tr
	H10	7	3	65	3	5	2		1	3				8			1
Mean		21	1	12	27	Tr	5	3	Tr	3	19	Tr	Tr	1	5	3	1

*Percent of total turpentine.
Tr - trace.

At a number of locations in Mexico (Chiapas), Guatemala, and El Salvador, I have observed trees with cones and foliage that appeared to be intermediate among *Pinus nubicola, P. oaxacana, P. pseudostrobus* var. *apulcensis*, and *P. montezumae*. In all instances the cones were much larger than those of typical *P. pseudostrobus*, the trees were five needled, and the bases of the fascicle bracts were not decurrent. In many instances *P. nubicola, P. pseudostrobus, P. montezumae, P. oaxacana*, and occasionally *P. rudis* formed a part of these mixed stands. It appeared that hybridization and back-crossing had been occurring for many years among these pines. Mirov (1961) stated that *P. oaxacana* apparently crosses naturally with *P. pseudostrobus* and probably also with some varieties of *P. montezumae*. Martínez (1948) pointed out that *P. pseudostrobus* and *P. montezumae* are very closely related. Extensive sampling and analyses



MAP 1. Distribution of *Pinus nubicola.*

of oleoresins from carefully selected trees could, with morphological studies of the cones and foliage, reveal the extent and nature of the hybridization that is occurring in many of these mixed stands.

Because the chemical composition of turpentine is inherited (Squillace, 1976), I believed that information about this character would provide valuable knowledge regarding identification and possible relationships of the new species. Accordingly, I took samples of xylem oleoresin from *Pinus nubicola* trees in Mexico, Guatemala, and Honduras. Results of the analyses are shown in TABLE 1. Information regarding collection and analysis of the oleoresin is given in the APPENDIX.

Although *Pinus nubicola* fits Martínez's and Loock's original concepts of a Pseudostrobus group of the Mexican pines, it (like *P. oaxacana* and *P. estevezii*) differs markedly from *P. pseudostrobus* in the chemical composition of its turpentine. Heptane and nonane are consistently present in the turpentine of *P. nubicola, P. estevezii,* and *P. oaxacana* but usually absent in *P. pseudostrobus* (see TABLE 2). Mirov (1958) stated that the gum turpentine of *P. oaxacana* contained 21 percent heptane, 51 percent d- and dl-α-pinene, 15–16 percent dl-limonene, 1.3 percent n-undecane, and 7.5 percent d-longifolene.[7] There

[7]Mirov's data were obtained from one sample, in which oleoresin from 25 trees (from near Rancho Nuevo, 25 km SW of San Cristóbal de Las Casas, Chiapas, Mexico) was combined. In other samples the percentages may be different. The presence of large quantities of heptane is significant.

TABLE 2. **Turpentine composition of xylem oleoresin from Pinus nubicola, P. estevezii, P. oaxacana, and P. pseudostrobus.**

	TAXON							
	P. nubicola (n = 31)		*P. estevezii* (n = 13)		*P. oaxacana** (n = 26)		*P. pseudostrobus* (n = 10)	
TERPENE	Mean[†]	% High[‡]	Mean	% High	Mean	% High	Mean	% High
Heptane	21	61	38	100	16	54		
Octane	1		2	4	15			
Nonane	12	61	11	55	10	35		
α -pinene	27	65	19	61	37	77	80	100
Camphene	Tr		3		3	12	1	
β -pinene	5	29	4		4	15	2	
Δ^3-carene	3	16	Tr		4	4	1	
Myrcene	Tr		9	30			11	40
α -terpinene	3	6			Tr			
Limonene	19	48	3	8	10	27	1	
β -phellandrene	Tr		4	15	Tr			
P-cymene	Tr						Tr	
Terpinolene	1		Tr		1	4	Tr	
α -fenchol					Tr		Tr	
Terpinene-4-ol	5	16			2	8		
β -caryophyllene					Tr			
Methyl chavicol	3	16	6	15	4	12		
α -terpineol	1	3			1	4	1	

*Samples collected by the author in Mexico (Puebla, Oaxaca, and Chiapas states) and Guatemala.
[†]Mean percent of total turpentine
[‡]Percent of trees having relatively high amounts. (For mathematical procedure see Squillace *et al.*, 1980).

thus appears to be a cluster of species within the Pseudostrobus group of Mexican pines that differ from typical *P. pseudostrobus* in the morphology of their cones and in the presence of heptane and nonane, usually in high amounts, in their turpentine. Further studies of oleoresins from the remaining taxa included in Martínez's sect. *Pseudostrobus* are required in order to clarify these relationships.

DISTINCTION AMONG PINUS NUBICOLA, P. ESTEVEZII, P. OAXACANA, AND P. PSEUDOSTROBUS

Although the principal identifying characteristics of the Pseudostrobus group (i.e., the smooth stems of young trees and the nondecurrent bases of the needle

TABLE 3. **Summary of differences among Pinus nubicola, P. estevezii, P. oaxacana, and P. pseudostrobus.**

	TAXON			
CHARACTER	P. nubicola	P. estevezii	P. oaxacana	P. pseudostrobus
FORM OF MATURE TREE	25-30 m tall; stem clear; crown open, rounded	12-20 m tall; stem often limby; crown dense, low, broadly rounded	25-30 m tall; stem clear; crown moderately dense, rounded	30-40 m tall; stem clear; crown narrow, rounded
LEAVES				
Number per fascicle	5 or 6 (occasionally 7, rarely 8)	5 (rarely 4)	5 (rarely 6)	5
Habit	Flexible, very drooping to pendent	Stiff, erect, not flexible	Flexible, slightly drooping	Flexible, slightly drooping to drooping
Dimensions	25-40(-43) cm x 0.6-1 mm	20-30(-35) cm x 1 mm	20-30(-33) cm x ca. 0.8 mm	20-25(-30) cm x ca. 0.7 mm
Anatomy	Hypoderm irregular, with many shallow penetrations into chlorenchyma; resin canals 3 (or 4), medial	Hypoderm irregular, with many shallow penetrations into chlorenchyma; resin canals 3 (to 5), medial (rarely with 1 internal)	Hypoderm uniform, with few slight penetrations into chlorenchyma; resin canals 2 (to 4), medial	Hypoderm uniform, with few slight penetrations into chlorenchyma; resin canals 2 (to 4), medial (rarely with 1 internal or external)
CONES	10-15 x 8-10 cm, asymmetric, reflexed	10-13 x 7-8 cm, asymmetric, usually reflexed	10-14 x 9-11 cm, asymmetric, usually reflexed	8-10 x 5-7 cm, slightly curved, not reflexed

TABLE 3. (*continued*).

CHARACTER	TAXON			
	P. nubicola	*P. estevezii*	*P. oaxacana*	*P. pseudostrobus*
CONE SCALES	20-25 mm wide, hard, strong, thick; apophyses unequally raised, transversely keeled; umbo small, margins slightly depressed, usually up-curved with small, persistent prickle; margin of apex with unequal projections	12-15 mm wide, hard, strong, thick; apophyses raised to subpyramidal, prominently transversely keeled; umbo raised, with persistent up-curved prickle; margin of apex smooth	12-20 mm wide, hard, strong, thick; apophyses with pronounced, unequal projections (to 22 mm long); umbo hard, with small, deciduous prickle; margin of apex smooth	15-18 mm wide; apophyses slightly raised to flat, slightly transversely keeled; umbo small, occasionally depressed, with small, deciduous prickle; margin of apex smooth
TURPENTINE	Usually large amount of heptane and smaller amount of nonane; usually large amounts of α-pinene and limonene; sometimes large amount of terpinene-4-ol; very small amount of myrcene and small but consistent amount of methyl chavicol	Usually large amount of heptane and smaller amount of nonane; often large amount of α-pinene; sometimes large amounts of myrcene, methyl chavicol, and ß-phellandrene	Usually large amount of heptane and smaller amount of nonane; usually large amount of α-pinene and smaller amounts of limonene and methyl chavicol	Heptane, octane, and nonane usually absent; usually very large amount of α-pinene, occasionally with large amount of myrcene; usually small amounts of Δ^3-carene, limonene, and α-terpineol
ALTITUDINAL RANGE (m)	1800-2400	800-1800	1500-3200	1600-3200

bracts) are shared by *Pinus nubicola, P. estevezii, P. oaxacana,* and *P. pseudostrobus,* the four species can be readily separated by combinations of characters (see TABLE 3).

Pinus nubicola is easily distinguished in the field from the other three species by its long, very drooping needles (see FIGURE 2) five or six (occasionally seven) in a fascicle, and its large, ovoid to long-ovoid cones with unusually wide, thick cone scales having unequal apical projections and a small depressed umbo (FIGURE 4). Cones of *P. oaxacana* are readily identified by their thick, stiff cone scales with unusual prolongation of the apophysis and umbo. *Pinus estevezii* can be distinguished from the other three taxa by its stiff, erect needles and its cones with thick, hard scales armed with a persistent up-curved prickle on the umbo. *Pinus pseudostrobus* is easily separated from the other three species by its much smaller cones having thin, flexible scales with a flat to slightly raised apophysis and a small umbo tipped by a small deciduous prickle (FIGURE 4).

A comparison of the oleoresin components also reveals significant differences among the four species (see TABLE 2). Outstanding among these was the presence of high amounts of limonene in 48 percent of *Pinus nubicola* trees. In addition there were trees of *P. nubicola* with high amounts of terpinene-4-ol (16%) and methyl chavicol (16%).

There appeared to be some population differences, but samples were too few for this to be determined with certainty. For example, all of the *Pinus nubicola* trees in the Guatemalan population had high heptane levels while only about half of the trees in the Mexican population did (see TABLE 1). It is interesting to note that the two trees in Honduras had the highest nonane levels of all the trees sampled.

As in most species, individual trees varied greatly in monoterpene composition. It would have been helpful to have oleoresin samples from *Pinus nubicola* trees growing in El Salvador. Unfortunately, the very unsettled political situation in that country, particularly in Depto. Chalatenango, made it unwise to attempt any resin collections there.

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APPENDIX. **Collection and analysis of oleoresins.**

COLLECTION

In Guatemala samples of xylem oleoresin were collected from nine trees of *Pinus nubicola* (d.b.h. 30–60 cm) growing near San José Pinula at the location described for the type.

At about 75 cm above the ground, a hole ca. 1 cm in diameter was drilled into the stem of each tree (22 February 1979) and a threaded glass vial was immediately screwed tightly into the hole. Three days later the vials were collected and each one covered with a threaded, gasketed cap. *Perry GUA.28-79* was collected as a composite voucher for these trees and has been deposited in the herbaria at GH and NCSC.

In Chiapas, Mexico, samples of xylem oleoresin were taken from 13 trees of *Pinus nubicola* (d.b.h. 35–90 cm) about 10 km west of San Cristóbal de Las Casas, near highway 190. Vials were placed on the trees 2 March 1979 and collected two days later. *Perry*

MEX.7B-12B and *Perry MEX.1B-14B* were collected as composite vouchers for these trees.

East of San Cristóbal de Las Casas, near Las Piedrecitas, oleoresin was collected from four trees of *Pinus nubicola* (d.b.h. 32–50 cm). Vials were placed on the trees 31 January and 1 February 1983 and collected the following day. *Perry M-12483, M-14283,* and *M-15183* were collected as vouchers for these trees.

West of San Cristóbal de Las Casas, near San José, oleoresin was collected from three trees of *Pinus nubicola* (d.b.h. 35–80 cm). Vials were placed on the trees 27–28 January and collected 30 January 1983. *Perry M-6083* and *M-7283* were collected as vouchers for these trees.

In Honduras oleoresin was collected from two trees of *Pinus nubicola* in the Departamento de La Paz, near the village of Las Trancas. Collections were made in October 1982 by W. S. Dvorak, Director of CAMCORE (Central America and Mexico Coniferous Resources Cooperative), and E. G. Ponce, staff member of ESNACIFOR (Escuela Nacional de Ciencias Forestales), Honduras. *Ponce H-8* and *H-10* were collected and deposited in the herbarium at ESNACIFOR, Siguatepeque, Honduras.

The sampling procedure described for collections in Guatemala was followed for all collections in Mexico and Honduras.

Analysis

Analyses of the pine-resin samples were performed by a chemical consulting laboratory, with the following gas-chromatographic conditions and equipment.

Turpentine from each sample was separated from the resin and extraneous matter by steam distillation (alkalinity was maintained to prevent acid isomerization).

The chromatograph used was a Varian Series 1700 with a thermal conductivity detector. A 10′ × ⅛″ diameter stainless-steel column packed with 15% carbowax 20M on "chromosorb W" was injected with 1.5 μl of sample. The injector temperature was 210°C, the detector temperature 225°C, and the column oven programmed from 75° to 220°C with a 4°C per minute temperature rise. The carrier gas was helium.

Components were identified by comparison of elution times against standard chromatographs made from combinations of pure compounds. When a question arose as to the identity of a compound, the sample was reshot with known components added until the presence of overlapping peaks or increase in peak size eliminated any uncertainty.